

DESCRIPTION

PHOTOELECTRIC CONVERSION DEVICE AND
MANUFACTURING METHOD THEREOF

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FIELD OF THE INVENTION

The present invention relates to a photoelectric conversion device, and more particularly, to a MOS type photoelectric conversion device and a manufacturing method thereof.

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BACKGROUND OF THE INVENTION

In recent years, in general, a photoelectric conversion device has been used as the solid state image-pick up device of a two-dimensional image input device centering on a digital still camera and a video camera recorder or has been utilized as a one-dimensional image reading device centering on a facsimile and a scanner, and has been much in rapid demand.

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As the photoelectric conversion device, a CCD (Charge Coupled Device) or MOS type sensor has been used. As a representative of the MOS type sensor, a CMOS photoelectric conversion device (hereinafter referred to as "CMOS sensor") has been put to practical use (see Japanese Patent Application Laid-Open No. 2001-332714).

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Fig. 7 is one example of a circuit block diagram of a solid state image-pick up device mounted with the CMOS sensor.

In Fig. 7, reference numeral 1 a photo diode (hereinafter referred to as [PD]) which converts a light into a signal charge, reference numeral 2 a transfer MOS transistor for transferring a signal charge generated in the PD, reference numeral 3 a floating diffusion region (hereinafter referred to as FD) for temporarily storing a transferred signal charge, reference numeral 4 a reset MOS transistor for resetting the FD3 and PD 1, reference numeral 5 a select MOS transistor for selecting an random line among an array, reference numeral 6 a source follower MOS transistor for converting the voltage of the signal charge of the FD3 and amplifying it by a source follower type amplifier, reference numeral 7 a reading out line which is used in common by a column for reading out a pixel voltage signal, and reference numeral 8 a constant current source for turning the reading out line 7 into a constant current. Although not shown, either or both of a circuit for processing a signal from this pixel and a drive circuit (shift resistor) for driving the transistor in the pixel are formed as a peripheral circuit in the same substrate.

Each pixel (except for the constant current source 8) is disposed in an array pattern, and

constitutes an image pick up device.

Fig. 8 is a schematic sectional view of the pixel of the image pick up device mounted with the CMOS sensor, and in particular, it is a view showing a portion of the PD 1 and the transfer MOS transistor 2 in Fig. 7. Reference numeral 11 denotes an n-type silicon substrate, reference numeral 12 a p-type well, reference numeral 13a a gate oxide film of the MOS transistor, reference numeral 13b a thin oxide film on a light receiving portion, reference numeral 14 a gate electrode of the transfer MOS transistor 2, reference numeral 15 an n-type anode of the PD1 (the n-type mode 15 is the same conductivity type as a signal charge and operates to storage and transfer the signal charge), reference numeral 16 a surface p-type region for turning the PD 1 into a berried structure, reference numeral 17 a select oxide film for separating pixels, reference numeral 18 an n-type high concentration region which forms a FD 3 and serves as a drain region of the transfer MOS transistor 2, reference numeral 19 a silicon oxide film for insulating the gate electrode 14 and a metal first layer 21, reference numeral 20 a contact plug, reference numeral 22 an interlayer insulation film for insulating the meal first layer 21 and a metal second layer 23, reference numeral 24 a interlayer insulation layer for insulating the second metal

layer 23 and a third metal layer 25, and reference numeral 26 a passivation film. In a color photoelectric conversion device, on the upper layer of the passivation film 26, there are further formed a color filter layer not shown, and also a micro lens for sensitivity improvement. A light incident from the surface passes through an opening portion having no metal third layer 25 and enters the PD. The light is absorbed inside the n-type anode 15 of the PD or the p-type well 12, and generates electron-hole pairs, among which the electrons are stored in the n-type anode 15.

Further, as features of the CMOS sensor, there is cited an advantage of a conventional CMOS process being utilizable, since, in a pixel portion, a PD formation well for forming a light receiving region and a peripheral circuit formation well for forming a drive device are the same conductive type. That is, the utmost features of the CMOS sensor are that, unlike a CCD, no specific production line is required, but that a low cost solid image pick up device can be produced by using an existing semiconductor production line.

Figs. 11A to 11D and 12A to 12C are views showing each of the well forming methods of the conventional CMOS sensor using an ordinary CMOS process.

Here, an example of using the n-type silicon substrate is shown.

First, a silicon thermally oxidized film 27 and a silicon nitride film 28 are formed on the n-type silicon substrate 11 (Fig. 11A).

After removing the silicon nitride film 28 of a desired region by the pattern of a photo resistor 29, a p-type impurity 30 is introduced (Fig. 11B) by ion implantation. After removing the photo resistor 29, when thermally oxidization processing is performed, a silicon oxidized film 31 is formed in the region alone, into which the p-type impurity 30 is introduced. Next, the silicon nitride film 28 is removed, and an n-type impurity 32 is introduced by ion implantation (Fig. 11C). At this time, since there is formed the oxidized film 31 on the region into which the p-type impurity 30 is introduced, the n-type impurity 32 is formed in a region other than the region where the p-type impurity 30 is formed self-align wise. Naturally, the oxidized film 31 is formed by a thick film so as not to be pierced at the implantation time of the n-type impurity 32.

As described above, after introducing the p-type impurity 30 and the n-type impurity 32 into the desired region, a thermo diffusion processing is performed so as to obtain a desired depth and a concentration profile (hereinafter referred to as

[impurity profile]), thereby forming a p-type well 12 and an n-type well 33 (Fig. 11D).

Subsequently, after removing all the oxidized films once,

5 the silicon thermal oxidized film 27 and the silicon nitride film 28 are formed again, and the desired region is subjected to patterning by the photo resistor 29, and the silicon nitride film 28 is subjected to an etching (Fig. 12A).

10 Finally, after performing electrical isolation by the select oxidized film 17, each well region for forming a MOS transistor, a resistor, a capacitor, a diode and the like is formed (Fig. 12B).

After that, a gate oxidized film 40 and a gate
15 electrode 41 of the MOS transistor are formed, and an n-type region 42 of the PD and a p-type region 43 of the surface are formed, and a source/drain 44 of the NMOS transistor and a source/drain 45 of the PMOS transistor are formed, and after going through a
20 wiring forming process (not shown), the solid state image pick up is completed (Fig. 12C).

Further, Fig. 12B shows from the left in order that a PD forming p-type well, a peripheral circuit p-type well, and a peripheral circuit n-type well are
25 formed by the select oxidized film 17, and there is an advantage of being able to adopt an easy process at a low cost by the minimum photolithographic

process and a self-aligning well forming method.

Further, though it is not the conventional CMOS process, as shown in Japanese Patent Application Laid-Open No. 2000-232214, there has been also

5 proposed a method of controlling the impurity profile by providing a buried type epitaxial region in the PD region.

Further, in Japanese Patent Application Laid-Open No. H01-243462, there has been disclosed a solid
10 state image pick up device comprising plural photoelectric conversion pixels and scanning means for reading out a signal of this photoelectric conversion pixel, wherein the photoelectric conversion pixel is formed inside an impurity layer
15 of concentration lower than the impurity layer by which scanning means is formed. This makes it possible to miniaturize a MOS transistor by forming a scanning circuit in a high concentration impurity layer according to a proportion reduction rule. In
20 addition, it has been disclosed that, by forming a photoelectric conversion portion inside a low concentration impurity layer, a depletion layer on the periphery of a photo diode is expanded so as to improve a light sensitivity.

25 Further, in USP 6,445,014, there is a description with regard to a periphery well in which a logical circuit is formed and a well in which a

pixel cell is formed. To be more in detail, a constitution is disclosed, wherein the well in which the pixel cell is formed is taken as a retrograde well, and the impurity concentration of the periphery well is reduced from the top toward the bottom of the well (see Fig. 12 of the U.S. Publication). Further, the impurity concentration is 1×10^{16} to 2×10^{18} atoms per cm^3 , and is taken as the same value. Further, with regard to depth of the well to be formed, the well which forms a PD region is deeper (see Fig. 11 of the U.S. Publication).

As described above, though the CMOS solid state image pick up device has an advantage of being able to use the existing CMOS forming manufacturing method, there are some problems involved in order to improve an imaging performance.

A first problem is that the impurity amount to be introduced to the peripheral circuit well region of the same conductive type as the PD well region is made the same as shown in the prior art (Fig. 11B), and for example, in this prior art, the impurity concentrations of the PD well region and the peripheral circuit p-type well region cannot be set separately. For example, to improve spectral characteristics of an incident light, it is not possible to diminish the impurity concentration alone of the PD well nor is it remarkably easy to control a

threshold value setting and the like of the MOS transistor provided inside the PD well without changing the concentration of the p-type peripheral circuit well.

5 A second problem is that the thermal diffusion processing after the introduction of the impurity into each of the PD well region and the peripheral circuit well region is often collectively performed as shown in (Fig. 11D). Hence, it is not possible in
10 principle to control the depth alone of the impurity profile of the PD well region, and so the impurity profile of the peripheral circuit well must be changed each time to improve the characteristics of the CMOS sensor, and this causes a great
15 inconvenience in terms of the design.

 Further, according to the constitution disclosed in Japanese Patent Application Laid-Open No. H01-243462, there is a point to be examined as follows. That is, in the constitution where the
20 concentration of the well to form the peripheral circuit is made high, the efficiency of collecting the charge in the photoelectric conversion portion may not be sufficiently achieved. This often grows to a greater problem to be solved as the pixel
25 becomes miniaturized and the sensitivity thereof is reduced.

 Further, according to the constitution

disclosed in USP 6,445,014, there is a point to be examined as follows. That is, though the depth of the well and the structure of the well are made different from the photoelectric conversion well and periphery well, since the impurity concentrations thereof are made the same, as described above, the efficiency of collecting the charge in the photoelectric conversion portion is often not sufficiently achieved.

10 Hence, an object of the present invention is to provide a photoelectric conversion device able to realize a PD well structure, which contributes to the improvement of an imaging performance, while using the existing CMOS manufacturing method.

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DISCLOSURE OF THE INVENTION

As means to achieve the above described object, the present invention proposes to independently control and form the impurity profile of the same conductive type peripheral circuit well as the PD well.

20 Hence, the present invention, in the photoelectric conversion device wherein a pixel including a photoelectric conversion device for converting a light into a signal charge and a peripheral circuit including a circuit for processing the signal charge outside the pixel region in which

the pixel are disposed on the same substrate, is characterized by comprising:

a first semiconductor region of a first conductivity for forming the photoelectric conversion device, the first semiconductor region being formed in a second semiconductor region of a second conductivity type; and

a third semiconductor region of the first conductivity type and a fourth semiconductor region of the second conductivity type for forming the peripheral circuit, the third and fourth semiconductor region being formed in the second semiconductor region; and

wherein the impurity concentration of the first semiconductor region is higher than the impurity concentration of the third semiconductor region.

Further, in the photoelectric conversion device, the first semiconductor region is characterized by comprising plural impurity regions, wherein each of the plural impurity regions has a peak of the impurity concentration.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A, 1B, 1C and 1D are views showing a portion of a well forming method of a CMOS sensor in a first embodiment of the present invention.

5 Figs. 2A, 2B, and 2C are views showing a portion of the well forming method of the CMOS sensor in the first embodiment of the present invention.

Fig. 3 is a schematic illustration of an impurity profile of a PD well region in the first
10 embodiment of the present invention.

Figs. 4A, 4B, 4C, 4D, and 4E are views showing a portion of the well forming method of the CMOS sensor in a second embodiment of the present invention.

15 Figs. 5A, 5B, and 5C are views showing a portion of the well forming method of the CMOS sensor in the second embodiment of the present invention.

Fig. 6 is a schematic illustration of an impurity profile of the PD well region in the second
20 embodiment of the present invention.

Fig. 7 is a circuit block diagram of the pixel of a solid state image pick up device mounted with a conventional CMOS sensor.

Fig. 8 is a schematic sectional view of the
25 pixel of the solid state image pick up device mounted with the conventional CMOS sensor.

Fig. 9 is a schematic sectional view of a pixel

portion and a peripheral circuit portion of the third embodiment.

Fig. 10 is a view showing a concentration profile in Fig. 9.

5 Figs. 11A, 11B, 11C, and 11D are views showing a portion of each well forming method of a conventional CMOS sensor using an ordinal CMOS process.

10 Figs. 12A, 12B, and 12C are views showing a portion of each well forming method of the conventional CMOS sensor using the ordinal CMOS process.

Fig. 13 is a view showing an example of a circuit block in case of adapting the photoelectric conversion device in a third embodiment of the present invention to a camera.

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BEST MODE FOR CARRYING OUT THE INVENTION

25 Next, embodiments of the present invention will be described with reference to the drawings. A well used in the description here indicates a region where a desired conductive type impurity is diffused, and

no restriction is imposed on its manufacturing method.
It has the same function as a semiconductor region.

<First Embodiment>

Figs. 1A to 1D, and 2A to 2C are views showing
5 a well forming method of a CMOS sensor in a first
embodiment of the present invention, particularly
forming method of a PD formation well and a
peripheral circuit formation well.

Here, the PD formation well includes, in
10 addition to a PD, a pixel circuit such as a transfer
MOS transistor, a FD, a reset MOS transistor, a
select MOS transistor, a source follower MOS
transistor for amplifying a signal, and the like.
Further, inside the peripheral circuit formation well,
15 there are formed a circuit for processing a signal
from the pixel, a drive circuit for driving the
transistor inside the pixel, and the like.

First, on an n-type silicon substrate 11, there
are formed a silicon thermally oxidized film 27 and a
20 silicon nitride film 28, which becomes a mask, and a
desired region is subjected to patterning by a photo
resistor 29 (Fig. 1A).

Next, the silicon nitride film 28 is subjected
to patterning by a dry etching (Fig. 1B), and a
25 select oxidized film 17 is formed by thermal
oxidization, and the nitride film is removed, and
each well region sectionalized by the select oxidized

film is secured (Fig. 1C).

Next, the region alone which becomes the PD formation well is subjected to patterning by a photo resistor 29a, and a desired p-type impurities 30a and 5 30b are introduced by ion implantation (Fig. 1D). Since the p-type impurities 30a and 30b are introduced into the PD region alone, a dose amount, an acceleration speed, and moreover, the number of times of ion implantation, and the like are allowed 10 to be set at random, and a thickness of the resist 29a is decided so as to become a mask material of the maximum acceleration energy. Further, though not illustrated, after performing a resist removing subsequent to implantation of the p-type impurities 15 30a and 30b, naturally, a heat treatment can be freely given to obtain a desired profile.

After having set the impurity profile of the well region for forming the PD in this manner, this time, the peripheral circuit p-type well region alone 20 is subjected to patterning by a photo resist 29b, and a p-type impurity 30 is introduced (Fig. 2A). Next, by a photo resist 29c, an n-type impurity 32 is sequentially introduced into a peripheral circuit n-type well region by the same method (Fig. 2B). 25 Finally, for optimization of the impurity profile of each well, a desired heat treatment is performed, thereby forming a PD well 34, a peripheral circuit p-

type well 12, and an n-type well 33 (Fig. 2C).

When the method of the present embodiment is used in this manner, an optimum well structure can be designed for each well.

5 Fig. 3 is a schematic illustration of the impurity profile cut along the line B-B of Fig. 2C, which is obtained in the case where the impurity profile of the PD well region in the present embodiment, particularly the above described PD well
10 region is subjected to patterning, and after that, the p-type impurity 30a is subjected to ion implantation plural times by energy of $5E11$ to $1E13$ atom/cm², and 40 to 700 keV, and the p-type impurity 30b by energy of $2E11$ to $1E14$ atom/cm², and 700 keV
15 to 2.7 MeV, and then, both the impurities are treated with a drive process at temperatures of 1000 to 1200 C° and under N₂ atmosphere for 0.5 to 6 hours.

 The p-type impurities 30a and 30b may be of the same material or of a different material, and if the
20 impurities are of the different material, the introduction by ion implantation is performed with a time shifted.

 Further, the impurity profile cut along the section A-A of the PD well region shown in the prior
25 art (Fig. 12B) is shown by a broken line in the drawing, and it can be seen that the present embodiment has a deeper p-type impurity profile

comparing to the prior art and the peripheral circuit formation p-type well. By this diffusion depth, a light carrier entering the PD well, particularly a spectral sensitivity having a deep infiltration
5 length in a long wavelength region can be much more improved.

Further, the PD formation well and the peripheral circuit formation well are constituted to be lower in the impurity concentration at the
10 substrate deep part side, comparing to a semiconductor substrate surface side. The impurity concentration of the periphery circuit forming well is lower in the impurity concentration, comparing to the PD formation well, and the depth of the well is
15 formed so as to become shallow. In this manner, the collecting efficiency of the charge of the PD is improved, and moreover, the production efficiency of the device can be improved.

Here, with regard to the place in which the
20 impurity concentrations of both wells are compared, it is a place sufficiently far away from the diffusion region for forming a source drain region of the MOS transistor, wherein, for example, the concentration may be compared at a place down below
25 the gate electrode and the source drain region and at the same depth from the substrate surface.

Further, in the present embodiment, since the

heat treatment is performed under the same heat treatment condition at the well forming time, both the PD region and the peripheral circuit region have not a clear-cut impurity concentration peak, and have
5 the same concentration at almost all the portions, and therefore, the impurity concentration may be compared in both the PD region and the peripheral circuit region.

<Second Embodiment>

10 Figs. 4A to 4E and 5A to 5C are views showing a well forming method of a CMOS sensor, particularly a forming method of a PD well and a peripheral circuit well structure in a second embodiment.

Figs. 4A to 4C are the same as the first
15 embodiment.

In the present embodiment, a resist patterning 29a is performed in a region alone which becomes a PD formation well, and a desired p-type impurity 30a is introduced by ion implantation similarly under the
20 same condition as the first embodiment.

Since the p-type impurity 30a is introduced into the PD region alone, a dose amount, energy or the number of times of ion implantation, and the like are allowed to be freely set.

25 Further, together with acceleration energy, the thickness of the resist 29a as a mask material can be adjusted. Further, in the present embodiment, as

shown in Figs. 4D and 4E, ion implantation is performed plural times separately. Subsequent to the ion implantation, a shallow semiconductor region 35a is formed by heat treatment, and after that, a deep semiconductor region 35a is formed next by ion
5 implantation so that it may be taken as a PD formation well. The p-type impurities 30a and 30b may be of the same matter or of a different material. The impurity concentration peak of the deep
10 semiconductor region 35b is preferably higher comparing to the impurity concentration peak of the 35a. This is for the 35b to function as a potential barrier to prevent a charge generated at the PD from leaking into a substrate and an adjacent pixel.
15 Further, with regard to the 35a, the impurity concentration of the impurity concentration peak is preferably higher than the impurity concentration peak of the p-type well, which forms the peripheral circuit. In this manner, the transfer voltage
20 (depleted voltage) at the signal transfer time from the PD to the FD can be controlled low.

Further, the p-type impurity region of the PD formation well has a common region with the p-type impurity region of the peripheral circuit well, and
25 moreover, the p-type impurity region deeper than the p-type impurity region of the peripheral circuit well may be disposed in the PD well alone.

After that, subsequent to Fig. 5A, it is the same production flow as subsequent to Fig. 2A.

Fig. 6 is a schematic illustration showing the impurity profile of the PD well, particularly the
5 impurity profile cut along the section C-C in Fig. 5C in the present embodiment.

The impurity profile cut along the section A-A of the PD well region shown in the prior art (Fig. 12B) is shown by a broken line in the drawing.

10 The p-type impurity region of the PD well comprises plural impurity regions having an impurity concentration peak, and the concentration of the deepest p-type impurity region is higher than the concentration of the next deepest p-type impurity
15 region.

As shown in the figure, when there exists the peak of a deep diffusion layer corresponding to the 35b in the deep diffusion region, since the charge generated in the region shallower than this peak
20 effectively reaches the PD of the surface side due to potential difference of the p-type diffusion layer, the sensitivity can be improved much more.

A Table 1 is a table comparing the embodiments in the present invention to the PD sensitivity of the
25 prior art by actual measurement, and shows that PD sensitivity of the present embodiment is improved by 10 percent or more comparing to the prior art, and

shows effectiveness of the present embodiment.

[Table 1]

	PRIOR ART	FIRST EMBODIMENT	SECOND EMBODIMENT
RELATIVE SENSITIVITY COMPARISON	1.00	1.10	1.16

Naturally, the pixel structure using the first
5 embodiment and the second embodiment as shown above
can be applied to Figs. 7 and 8 shown earlier.
Further, the method of the present embodiment not
only can avoid a risk such as an autodoping effect, a
crystal defect, and the like which generates at the
10 time of an epitaxial growth for the process (Japanese
Patent Application Laid-Open No. 2000-232214) using
the buried type PD, but also makes it possible to
design an ideal PD well shown in Fig. 2C in the first
embodiment or Fig. 5A in the second embodiment
15 totally independent from the peripheral circuit
region by unrestricted combination of the ion
implantation and the ordinary heater treatment.

<Third Embodiment>

The point in which the present embodiment is
20 different from the first and second embodiments is
that a well by which a PD is formed is constituted by
plural impurity regions having an impurity
concentration peak, and a peripheral circuit
formation well is also constituted by plural impurity

regions having the impurity concentration peak. The forming process can be formed by the same step as the process shown in Figs. 4A to 4E and 5A to 5C.

However, an implantation step of the impurity 31 is
5 performed by different acceleration voltage and dose amount.

A schematic sectional view of a PD formation region and a peripheral circuit formation region of the present embodiment will be shown in Fig. 9. In
10 Fig. 9, reference numeral 101 denotes an n-type silicon substrate (semiconductor substrate). The n-type silicon substrate 101 is formed with p-type semiconductor regions 108 to 110 (first to third semiconductor regions) including regions having
15 impurity concentration peaks in the n-type silicon substrate 101, and a substrate surface is formed with an element isolation region 102, a gate electrode 103 of a transfer transistor, a readout region 104, a storing region 105 (n-type semiconductor region of
20 which conductivity type is the same as a signal charge, and which operates to storage and transfer the signal charge) of a photo diode, a surface p region 106 of the photo diode, and a p-type semiconductor 111. A light shielding layer 107 is
25 provided with an opening portion, which shields a light toward the regions other than the photo diode. Further, reference numeral 801 denotes p-type

semiconductor regions (fourth and fifth semiconductor regions) having impurity concentration peaks for forming the peripheral circuit. As evident from Fig. 8, the PD formation wells (first semiconductor region to third semiconductor region) are formed up to the depth of the substrate, comparing to the peripheral circuit formation well. Although to be described later, the impurity concentration peak concentration of the first semiconductor region 110 is set higher than the peak concentrations of the fourth and fifth semiconductor regions.

According to such a constitution, both the PD formation well and the peripheral circuit formation well can be formed into desired well profiles by the dose amount and the acceleration voltage at the time of the impurity ion implantation. Further, since the peak concentration of the first semiconductor region 110 formed at the substrate deep portion of the PD formation well can be set high, charge collection efficiency can be improved.

The impurity concentration profile of the well in which the PD is formed becomes a profile as shown in Fig. 9. The highest concentration of the impurity concentration peak is of the first impurity region 110 formed in the deepest location of the substrate, that is, the deepest portion of the substrate as compared to a light receiving surface, and the next

highest concentration is of a second impurity region 108 in the vicinity of the well and an inverse conductive n-type region. The third impurity region 109 is lower in the impurity concentration peak than
5 the impurity regions 108 and 110.

Next, the impurity concentration relation of each semiconductor region will be described. The reason of the impurity concentration peak concentration of the first semiconductor region being
10 the most highest is that the charge generated in the deep portion of the substrate is not allowed to leak into the substrate side, but is made as a potential barrier to be used as a signal. The third semiconductor region 109 is formed at a low
15 concentration compared to the first semiconductor region 110 in order to collect the signal charge generated in the vicinity of the first semiconductor 110 at the surface side. Further, the second semiconductor region formed close to the surface
20 forms the impurity concentration higher comparing to the third semiconductor region 109, which has a function to control the width of a depletion layer in the joint with the storing region 105 of the photo diode. In this manner, a depleted voltage of the PD
25 can be lowered, and a total reset and total transfer of the PD can be made without raising a potential for resetting the readout region 104. Further, a

transfer gate voltage required for the reset and transfer of the PD, that is, an ON time voltage given to the gate electrode 103 of the transfer transistor can be made small, and a dynamic range can be secured without causing a rise of the power source voltage.

Fig. 10 is an explanatory drawing of concentration profiles in a vertical direction of the PD portion, and shows concentration profiles cut along the lines A-A' and B-B' of Fig. 9. Reference numeral 206 shows a concentration profile of a surface p region of the photo diode, and corresponds to reference numeral 106 of Fig. 9. The concentration profile 206 can be formed by implantation of boron or fluoroboron. Reference numeral 205 denotes a concentration profile of the storing region of the photo diode, and corresponds to reference numeral 105 of Fig. 9. 205 can be formed by implantation of phosphor or arsenic. Reference numeral 208 denotes a concentration profile of the impurity region close to the storing region 205, and corresponds to reference numeral 108 of Fig. 9. Reference numerals 209 and 209' denote concentration profiles of an intermediate region, and correspond to reference numeral 109 of Fig. 9. In Fig. 10, an intermediate region is formed by having two stage peaks. In this manner, the present embodiment is effective also for the case where the concentration

profile is formed by ion implantation of plural stages aligning with a desired structure. The concentration profiles 209 and 209' can be formed by double implantation of boron or fluoroboron.

- 5 Reference numeral 210 denotes a concentration profile of the impurity region positioned at a location deeper than 208 and 209, and corresponds to reference numeral 110 of Fig. 9. A description on the p-type semiconductor region 111 will be omitted.
- 10 Concentration profiles 211 and 212 correspond to reference numerals 801 and 802 of Fig. 9. As evident from Fig. 10, the impurity concentration peak concentration of the first semiconductor region 110 is higher than those of the fourth and fifth
- 15 semiconductor regions 801 and 802. More preferably, the impurity concentration peak concentration of the second semiconductor region 108 is also set higher in impurity concentration peak than those of the fourth and fifth semiconductor regions. In this manner, as
- 20 described above, the collection efficiency of charge can be improved, and moreover, the depleted voltage can be kept low.

Because of the above described functions, specific values of the peak concentration position

25 and the peak concentration of each semiconductor region will be shown as follows. A first semiconductor region 210 has an impurity

concentration peak concentration of $1 \times 10^{16} \text{ cm}^{-3}$ to $1 \times 10^{18} \text{ cm}^{-3}$, and the depth of the peak located is 2.0 μm to 4.0 μm from the substrate surface. A second semiconductor region 208 has a concentration of the impurity concentration peak of $2 \times 10^{15} \text{ cm}^{-3}$ to $2 \times 10^{17} \text{ cm}^{-3}$, and the depth of the peak located is 0.5 μm to 1.0 μm . The peak concentrations of third semiconductor regions 209 and 209' are 1×10^{15} to $5 \times 10^{16} \text{ cm}^{-3}$, and it is effective to set the depth of the peak at 0.8 μm to 2.5 μm .

Further, the peak concentrations of fourth and fifth semiconductor regions are preferably set $1 \times 10^{16} \text{ cm}^{-3}$ to $1 \times 10^{18} \text{ cm}^{-3}$, and the depth of the peak is preferably set at 0.8 μm to 2.5 μm .

According to the constitution of the present embodiment thus described, both the PD formation well and the peripheral circuit formation well can be formed into desired profiles by the dose amount and the acceleration voltage at the time of the impurity ion implantation. Further, at this time, the peak concentration of the first semiconductor region 110 formed at the substrate deep portion of the PD formation well can be set higher than the peripheral circuit region, so that a charge collection efficiency can be improved.

(Application to Digital Camera)

Fig. 13 shows an example of a circuit block in

case of applying a photoelectric conversion device according to the first to third embodiments of the present invention to a camera.

In front of an imaging lens 302, there is a shutter 301, which controls an exposure. A light quantity is controlled by a diaphragm 303 as occasion demands, and an image of an object is imaged into a photoelectric conversion device 304. The photoelectric conversion device 304 uses the photoelectric conversion device of the present invention. The signal outputted from the photoelectric conversion device 304 is processed at an image pick up signal processing circuit 305, and is converted from an analogue signal to a digital signal by an A/D converter 306. The outputted digital signal is further subjected to an arithmetic processing at a signal processing unit 307. The processed digital signal is stored in a memory unit 310 or transmitted to external equipment through an external I/F 313. The photoelectric conversion device 304, the image pick up signal processing circuit 305, the A/D converter 306, and the signal processing unit 307 are controlled by a timing generator 308, and in addition, the whole system is controlled by a unit controlling whole and arithmetic operation 309. To record an image in a recording medium 312, the output digital signal is recorded

through an I/F unit 311 controlling recording medium controlled by the unit controlling whole and arithmetic operation.

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This application claims priority from Japanese Patent Application No. 2004-137411 filed on May 6, 2004, which is hereby incorporated by reference herein.

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